UCRL- 84052
PREPRINT

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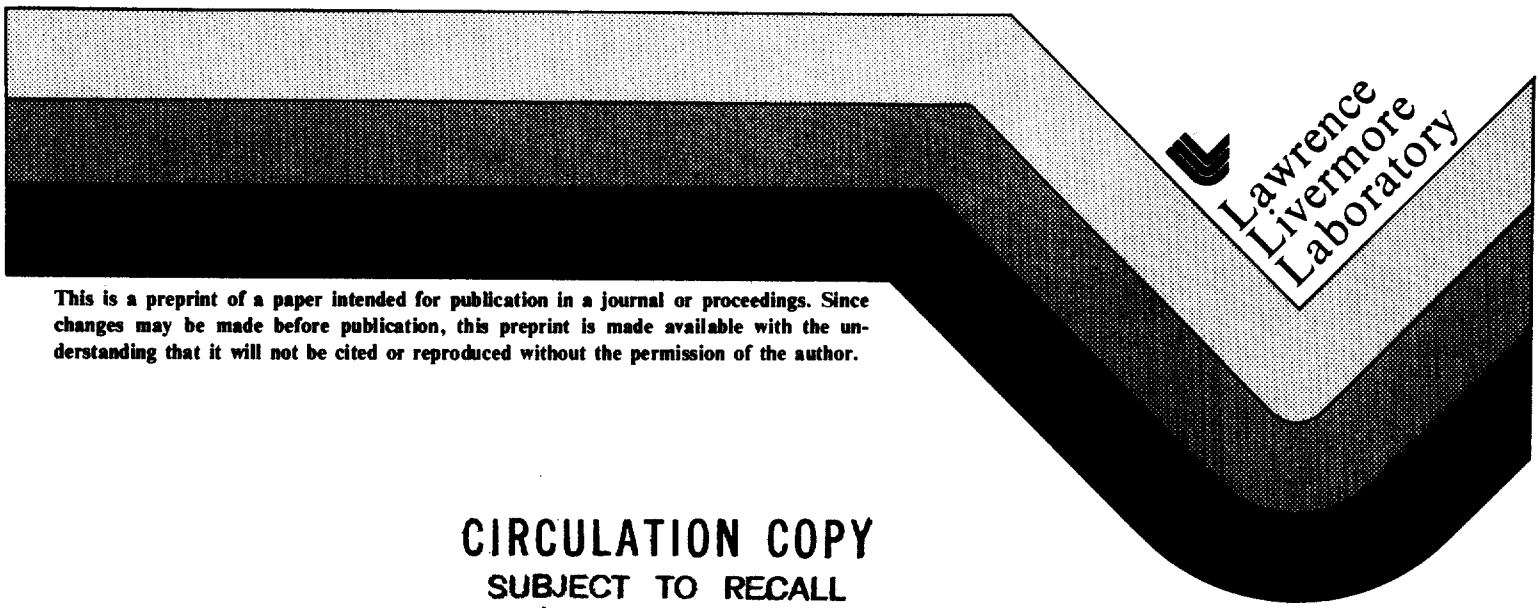
Eleventh Symposium on Fusion Technology
Oxford - United Kingdom
September 15-19, 1980

September 3, 1980



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MECHANICAL TECHNOLOGY UNIQUE TO LASER FUSION EXPERIMENTAL SYSTEMS*

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Abstract

Hardware design for laser fusion experimental machines has led to a combi- nation of engineering technologies that are critical to the successful operation of these machines. These large opto-mechanical systems are dependent on extreme cleanliness, accommodation to efficient maintenance, and high stability. These three technologies are the primary mechanical engineering criteria for laser fusion devices.

1. INTRODUCTION

Structural and mechanical hardware for most fusion devices normally fall within classical lines of design and fabrication. In the past six years, however, with the growth of inertial confinement, a series of experimental machines -- built and operated at the Lawrence Livermore National Laboratory (LLNL) -- have required new engineering approaches that depart from the classical lines. These new approaches have created a mechanical technology that is unique to laser fusion experimental systems. We are applying much of this technology to Nova, the latest in the LLNL series of neodymium-glass laser systems, which will irradiate and implode deuterium pellets. Nova, whose 10 laser beams will provide an 80- to 120-KJ fusion capability in early 1983, is expected to demonstrate scientific breakeven.

Nova is being constructed in two phases (fig. 1). The first phase is housed in a building adjacent to the Shiva laser. After Phase I, with 10 beams operational, Shiva will be shut down and upgraded into 10 Nova laser beams and combined with the original beams to provide a full 20-beam capability.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

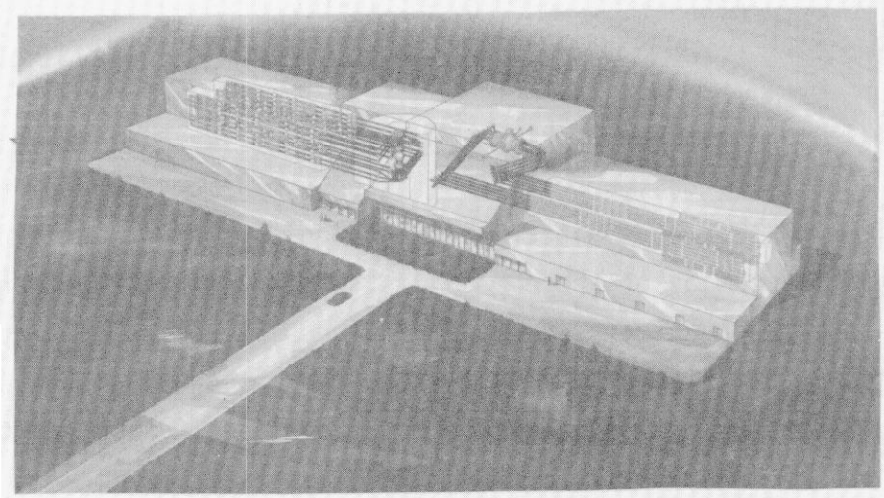

Fig. 1. Phase 1 of Nova shows Nova installed separately while Shiva is still in operation.

Four systems were built preceeding Nova. These were Cyclops, a 1-KJ, 20-cm-aperture laser; Janus, LLNL's first two-arm, 10-cm-output-aperture, target-irradiation facility; Argus, a two-arm, 5-kJ, 20-cm-output-aperture laser; and Shiva a 20-arm, 10-kJ, 20-cm output-aperture laser.

The experiences of designing, building, and operating these systems led to the development of critical concepts and technology needed for the successful operation of systems like Nova.

2. CLEANINESS

The sensitive nature of huge optical systems requires that particulate contamination be minimized [1-2]. Particles on optical surfaces result in surface damage when exposed to flashlamp or laser light. Consequently, in design, one must consider fasteners that do not generate contaminants, as well as materials and assembly procedures that are contaminant-free.

Early amplifiers were designed using design philosophy normally acceptable in electro-mechanical and opto-mechanical devices. This implied standard surface treatments, standard screw fasteners, and standard part interfaces. It was soon recognized that the traditional

way of doing things was not acceptable. Mechanical fasteners had to be replaced with devices such as springs that hold parts together without rubbing or scraping surfaces, such as a threaded shaft in a threaded hole. Sliding surfaces generate wear particles in sizes and numbers that depend on surface hardness, loading, sliding distance, and the materials involved.

Surface cleaniness of all mechanical parts means that fingerprints and particles as small as 1 to 10 m cannot be tolerated. Hardware design is heavily influenced by handling considerations. Every source of particulate contamination is analyzed in the design process, and we make every effort to eliminate the source. The size of these components on Nova has increased almost fourfold over Shiva and earlier machines. The handling and cleaning of these large, heavy, and fragile parts, in a clean-room environment, must be done with great care to ensure contaminant-free surfaces. For optical surfaces, careful solvent wiping is most effective. For mechanical parts, liquid solvent spray with pressures up to 1000 psi is most effective (fig. 2).

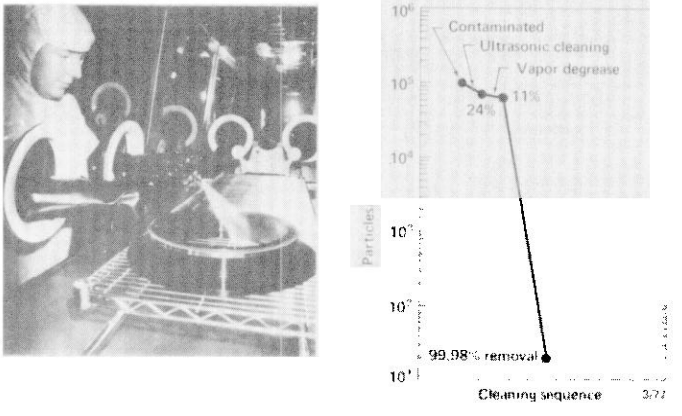

Fig. 2. High pressure spray cleaning of parts.

Care must be taken to eliminate cracks, seams, crevices, and recesses that tend to accumulate dirt and act as a virtual source of contaminants. Surfaces must not be porous or rough; they must be cleanable. Even exterior surfaces on components can cause contamination in the clean room in the form of paint chips. The entire system must be

designed so that everything is reliably cleanable and easily maintained. The Shiva and Nova lasers are housed in a class-1000 clean room in which the maximum concentration of airborne particles 0.5 m in diameter and larger is 1000 per cubic ft.

3. MAINTENANCE

Efficient maintenance, which leads to maximum performance and operational efficiency, can only be achieved by dedicated design. To achieve efficient maintenance leading to more useful energy on target, one must have simple designs and fewer parts so that parts can be assembled and inspected more easily. Only by this total awareness of system cleanliness can one achieve an acceptable operation time and acceptable beam quality as seen by the before and after beam photographs (fig. 3) of the Argus laser [3].

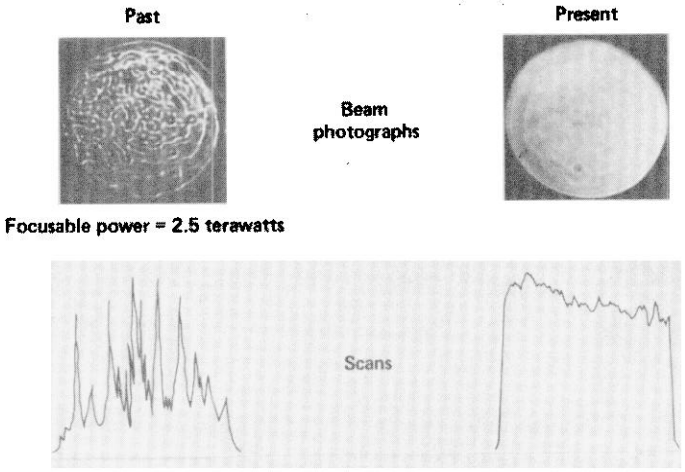

Fig. 3. Example of improved beam quality due to maintenance.

4. LASER SYSTEM

Nova Phase I consists of 10 parallel, linear laser chains (fig. 1) driven by a master oscillator. Each chain is a series of amplifier stages up to 46-cm aperture with 180 m of optical propagation path. Spatial filters between the amplifier stages provide the functions of filtering, relaying, and beam expanding. They are vacuum tubes with lenses at each end and a pinhole at the focal point. As a filter, they reduce high frequency spatial noise which damages optical surfaces. As a relay they project a clean image at the beam front to the input of the next spatial filter, through each amplifier stage. Both functions reduce damaging peak intensities along the beam path.

There are seven of these units in each laser chain, with output apertures that range from 3.75 to 74 cm. Spatial filter alignment is the most critical of beam line components.

The vacuum tubes are made of stainless steel tubing. Rolled taper sections of stainless steel are used for the larger filters, and the diameter of the spatial filter decreases near the pinhole (fig. 4).

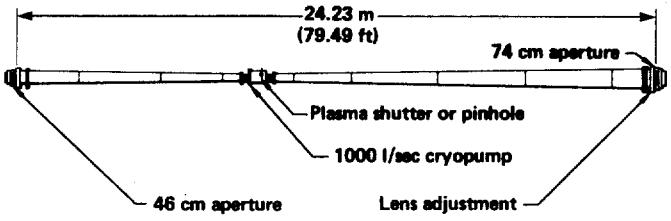

Fig. 4. This is the largest spatial filter in the Nova chain. It is an f/20 lens system with a 46-cm-aperture input lens and a 74-cm-aperature output lens.

The final spatial filter in each chain contains a plasma shutter that projects a critical density of aluminum plasma across the beam path at the pinhole immediately after the beam pulse passes, thus preventing the pulse from reflecting back into the chain [4]. Filters will be fitted with an adjusting mechanism permitting each lens in the system to be adjusted independently under full vacuum. The range of adjustment will be $\pm$12 mm in the x and y directions across the beam and $\pm$50 mm in focus along the beam line. This adjustment capability will allow the long vacuum chambers between the lenses to be rigidly mounted to the spaceframe with only a rough adjustment to the beam line. Motorized pinhole manipulators are used to adjust the pinhole to the focal point. Each filter is pumped individually with either ion-vacuum or cryogenic pumps. Three of the seven units are self-contained and portable, for easy maintenance. The larger sizes are designed so that the tubes stay fixed to the spaceframe and the lens holders are removed for maintenance.

The 46-cm-aperture disk amplifier (fig. 5) incorporates all the latest innovations of amplifier technology. Its improved performance, higher pumping efficiency, cost effectiveness, and simplicity make it the most impressive disk amplifier in LLNL history. It uses rectangular pumping in which the flashlamp light passes through the laser disks before striking other flashlamps. Also, the large laser disk is split into halves, which reduces the amplified spontaneous emmission. This ASE loss has previously made large-aperture amplifiers less attractive. The disks are spring-mounted in electro-formed ellipitical disk holders which are mounted in vertical orientation in kinematic mounts. All reflective surfaces are silver-plated. The pump volume is held to minimum dimensions, and there are no light traps. The pump cavity is a reflective box electrically isolated from an outer box as part of the protective grounding system. This box serves as the structural spine and as a hermetic seal. The boxes -- stacked end-to-end, very closely coupled -- act as a continuous amplifier, reducing end losses.

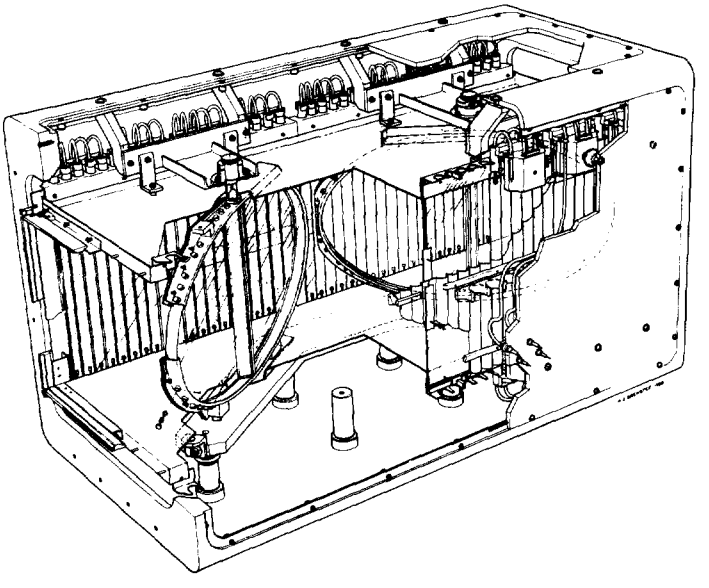

Fig. 5. 46-cm split disk amplifier with transverse flashlamps.

The remainder of each chain consists of isolation stages and turning mirrors. The isolation stages are either Pockels cells,

Faraday rotators, or plasma shutters. All protect the optical surfaces from back-reflections and subsequent damage. The mirrors, which direct the beam toward the target, range in size from 10 cm to more than 100 cm. They are mounted in stable, high-resolution gimbals.

5. STABILITY

Making the components of a system accessible, for optimum maintenance, is directly associated with system stability. All components must be supported in a way that allows quick inspection, repair, replacement, and rebuilding, yet meets the stability requirement for a multiple beam system to hit targets no larger than several hundred micrometers. Thermal and vibrational stability are the primary requirements. Seismic resistance, damping, and strain-free mounts are secondary but essential needs.

5.1 Spaceframe stability

The Nova spaceframe rigidly supports and maintains the alignment of the total laser system. Three structures that support the laser -- laser frame, switchyard frame, and target frame -- are shown in (fig. 6).

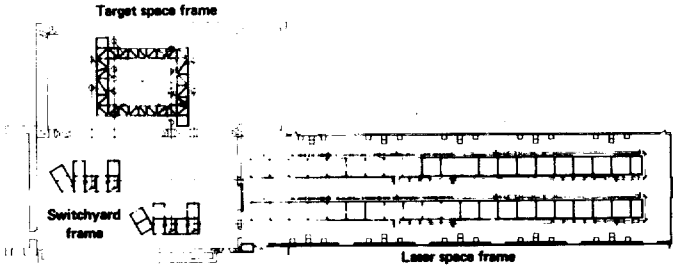

Fig. 6. Plan view of Nova's three spaceframes.

Two types of disturbances limit the pointing accuracy of the laser: thermal drift and microseismic ground motion. Thermal drift results from temperature variations between air-conditioning zones within the laser bay. Microseismic activity from vehicles, people, and air-conditioning blower vibration produces a continuous vibrational input to the spaceframe. Thermal drift and microseismic activity together tip and bend the steel structure, causing the turning mirrors and spatial filters

to rotate with resulting laser beam drift or jitter around the target [5]. The five air-conditioning zones within the laser bay are rigidly held to $\pm$ 1/2^{o}C variation. If this maximum variation were to exist between adjacent zones within the laser bay, it would result in a 0.7-μrad twist to the structure. The twist would cause the spatial filters to tip, which would produce a maximum 2.3-μm deflection at the target. This effect is decreased by the structure's thermal inertia, which is large compared with the rapid rate of change capability of the air-conditioning system.

Microseismic effects were modeled by simulating the motion of the frames using SAP4, a structural analysis code. This is the first time that we have simulated the entire spaceframe. The undeformed laser frame and two higher-order mode shapes are shown in (fig. 7).

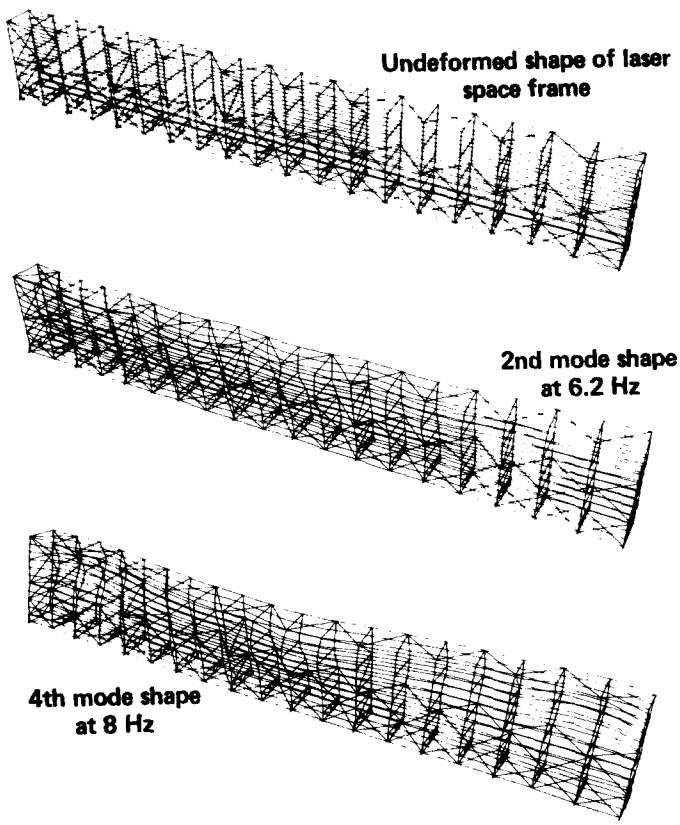

Fig. 7. Dynamic analysis of spaceframe shows two mode shapes.

The model was driven by an acceleration-forcing function previously measured in the Shiva laser bay. The resulting spaceframe motion was used to predict jitter at the target. The worst-case jitter was 4.3 μm,

with the largest contribution coming from rotation of the mirrors on the switchyard frame. This is within the predicted accuracy of the alignment system.

5.2 Earthquake stability

On January 24, 1980, at 11:00 a.m., an earthquake measuring 5.5 on the Richter scale shook the Livermore Valley [6]. There were three very pronounced shocks; the first at 5.5 on the Richter scale followed by two others, at 5.2 and 4.8. The Shiva spaceframe was shaken out of alignment. Shiva consists of two frames; a laser frame and a target frame. Components on each frame stayed within alignment with respect to each other, but the target frame moved with respect to the laser frame. Shearing of the seismic anchor bolts on the target frame was responsible for this misalignment. The reason for the seismic anchor failing lies in the unique design of the frame as an optical bench, not as a building or as a normal load bearing structure. This was the third in a series of earthquakes for Shiva, the first occurring on June 20, 1977 at a magnitude of 4.7 on the Richter scale and an epicenter 2 miles away. The second quake was on August 6, 1979, with a magnitude of 5.9 and the epicenter 60 miles away. There was no damage or misalignment from these earlier earthquakes.

The frames are fixed at a single point; all other support points are on rollers and allowed to expand in all directions from this point. This is to prevent distortions of the structure from thermal gradients if the air-conditioning system fails. The fixed point is a seismic anchor, which has the primary function of resisting a horizontal earthquake acceleration, in any direction, equal to 25% of the acceleration of gravity. For optical stability, all components on the frame itself are mounted with very stiff supports. All interfaces between these component supports and the spaceframe are designed with bolts approximately twice as strong as the floor bolts. None of these interface bolts failed. A major problem can occur if the frame is tied too firmly to the floor; large earthquake forces can be transmitted through the frame with subsequent structural damage, component damage, and possibly falling components.

The target frame, weighing 495,000 lb, was jacked up approximately 0.25 in. with 15 hydraulic jacks; all bearings were removed, inspected, repaired, and reinstalled. The frame was lowered onto these bearings, moved to its original position, and securely anchored. Throughout this maneuver the frame was under complete safe control in case of another quake.

Investigation indicates that all the bolts did not resist the load simultaneously that there was some bending on the bolts, and that they failed in a zipper fashion in tension and shear.

In evaluating the Shiva anchor bolt failure, it seemed apparent the ground acceleration was greater than the 0.25 g design value.

Bolt tests, combined with evaluation of the spaceframe reaction, indicate an acceleration between 0.4 and 0.6 g. Nova anchors will have to be designed to resist a 0.5 g acceleration and will have controlled breakaway anchors.

Acknowledgments

The author recognizes the outstanding contributions of the many mechanical engineering contributors throughout development of the laser fusion machines at LLNL. I would also like to acknowledge the leaders of the program -- John Emmett, John Holzrichter, Robert Godwin, Bill Simmons, Tom Gilmartin, and Jim Glaze -- for their leadership, support and guidance.

I would like to especially acknowledge the Nova design team for their efforts on this difficult project: G. Bradley, J. Braught, M. Demos, F. Frick, B. Gim, G. Lee, C. McFann, H. Rien, I. Stowers, and H. Patton.

References

[1] PATTON, H. G., STOWERS, I. F., JONES, W. A., and WENTWORTH, D. E.; Status Report on Cleaning and Maintenance Laser Disk Amplifiers, LLNL, Livermore, California - UCRL 52412 (1978)

[2] STOWERS, I. F., PATTON, H. G.; Cleaning Optical Surfaces, LLNL, Livermore, California - UCRL 80731 (1978)

[3] HUNT, JOHN; Image Recycling, LLNL, Laser Focus, May 1979

[4] STOWERS, I.F., et al; Plasma shutter

[5] Laser Fusion Monthly, March 1980; Editor W. F. Krupke, LLNL, Livermore, California

[6] HURLEY, C. A.; Some Comments on the Shiva Spaceframe Earthquake Damage, LLNL, Livermore California - UCID 18644

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